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HERA PROSPECTS ON COMPOSITENESS AND NEW VECTOR BOSONS

P. Chiappetta[a] and J.-M. Virey[a,b,1]

[a] Centre de Physique Théorique, UPR 7061,
CNRS Luminy, Case 907, F-13288 Marseille Cedex 9.

[b] and Université de Provence, Marseille, France.

Abstract

The absence of deviations from the Standard Model for the differential cross section $\frac{d\sigma}{dQ^2}$ at HERA is used to set limits on electron quark compositeness scale and on new vector bosons, especially the hadrophilic one recently introduced as a possible explanation for LEP/SLC and CDF anomalies.

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[1] Moniteur CIES and allocataire MENESR.
email : chiapeta@cpt.univ-mrs.fr

1 Introduction.

The $e^{\pm}p$ HERA collider, in which electrons and positrons of 27.5 GeV of energy collide with 820 GeV protons, can extend the search for compositeness [1] in the electron-quark channel or new gauge bosons [2] far beyond the kinematical limit thanks to indirect effects. The observable we will deal with is the differential cross section $\frac{d\sigma}{dQ^2}$, where Q^2 is the positive squared transfer momentum. The purpose of this letter is to set limits on electron quark compositeness and new vector gauge bosons from present HERA measurements[3] and future prospects.

2 Bounds from present data.

The first analysis, we will perform, relies on purely inclusive $H1$ measurements[3] in deep inelastic scattering from ep collisions with an integrated luminosity of $0.909 pb^{-1}$ for electron and $2.947 pb^{-1}$ for positron beams. The measured Q^2 range lies between $200 GeV^2$ and $2.10^4 GeV^2$. A χ^2 analysis of $e^{\pm}p$ differential cross sections - including statistical and systematical errors added in quadrature except for an overall normalization uncertainty- is performed. The overall normalization errors are 3.5% (resp 1.8%) for e^-p (resp e^+p) data.

If quarks and leptons have a substructure, the contact interaction, on which our derivation is based, is given by the lagrangian [1]:

$$\begin{aligned} L_{NC} = \sum_q &(\eta_{LL}(\bar{e}_L\gamma_\mu e_L)(\bar{q}_L\gamma^\mu q_L) + \eta_{RR}(\bar{e}_R\gamma_\mu e_R)(\bar{q}_R\gamma^\mu q_R) \\ &+\eta_{LR}(\bar{e}_L\gamma_\mu e_L)(\bar{q}_R\gamma^\mu q_R) + \eta_{RL}(\bar{e}_R\gamma_\mu e_R)(\bar{q}_L\gamma^\mu q_L)) \end{aligned} \quad (1)$$

where $\eta_{IJ} = \epsilon\frac{g^2}{\Lambda^2}$ (with $\epsilon = \pm 1$, from now Λ means Λ_{eq}). The present HERA limits, which can be inferred from the absence of deviations from SM, are given in the following table (assuming $g^2 = 4\pi$).

Λ (TeV)	Λ_{LL}	Λ_{RR}	Λ_{LR}	Λ_{RL}
$\epsilon = +1$	2.3	2.3	2.5	2.5
$\epsilon = -1$	1.0	1.0	1.2	1.2

Table 1: Present HERA limits on Λ at 95% CL [3].

In fact, the world present limits on Λ come from the search for an excess of high mass dileptons events at Tevatron [4], which gives for a data sample of $L = 110 pb^{-1}$ (Runs Ia & Ib) the values $\Lambda^+ \geq 2.6$ TeV and $\Lambda^- \geq 3.8$ TeV, where the sign $+$ or $-$ corresponds to ϵ.

At low energies, compared to the mass of the heavy particle, this lagrangian can also describe the effect of a vector boson exchange.

The Z' current, written in terms of left handed C'_L and right handed C'_R couplings to fermions, reads:

$$J_\mu^{Z'} = \frac{1}{\sin\theta_W \cos\theta_W} \bar{f}\gamma_\mu (C'_L \frac{(1-\gamma_5)}{2} + C'_R \frac{(1+\gamma_5)}{2}) f \tag{2}$$

In order to fix the normalization we also give the fermionic couplings to the standard model Z : $C_L = I_3 - Q\sin^2\theta_W$ (with $I_3 = \pm\frac{1}{2}$) and $C_R = -Q\sin^2\theta_W$, Q being the fermion electric charge and θ_W the Weinberg angle ($\sin^2\theta_W = 0.2319$).

The previous compositeness limits given in table 1 can be used to set limits on the Z' couplings to fermions for a fixed Z' mass, according to:

$$C'_e C'_q \sim (\frac{\sin^2\theta_W \cos^2\theta_W}{\alpha})(\frac{M^2_{Z'}}{\Lambda^2}) \tag{3}$$

Assuming typical values like $M_{Z'} = 1$ TeV and $\Lambda = 2.5$ TeV (i.e. the most favorable case) one gets:

$$C'_e C'_q \sim 4. \tag{4}$$

Recently, the CDF collaboration[5] has reported an excess of jets at large transverse energy (more precisely for $E_T \geq 250$ GeV). A possible non standard -i.e. beyond SM- explanation could be either existence of a quark substructure (at a scale $\Lambda_{qq} \sim 1.6$ TeV), or existence of an extra heavy neutral vector boson, of mass around 1 TeV. It has to couple dominantly to quarks, in order to explain also the LEP/SLC anomalies[6] in the heavy quark sector i.e. deviations from the SM on R_b and R_c [7] [8]. This Z' provides an additional contribution to top production[9], still compatible with present measurements. The potentialities of LEP2 [7] and polarized RHIC[10] for the observability of hadrophilic Z' effects have also been explored. It is of some importance to investigate if the preferred range for hadrophilic Z' couplings to fermions is ruled out by present data from HERA. Without any assumption on the underlying theory[7] these couplings can be expressed in terms of ratios ξ_{Vf} and ξ_{Af} between the Z' couplings and the Z couplings. In the leptophobic option[8] equality of the left-handed couplings within one $SU(2)_L$ doublet, labelled by the parameter $C'_L = x$,is imposed whereas the right-handed couplings C'_{Rq} for up and down type quarks (labelled as y_u and y_d in [8]) are left free. The relationship between hadrophilic and leptophobic options is given by:

$$\xi_{Vf} = \frac{C'_{Lf} + C'_{Rf}}{I_3 - 2Q_f \sin^2\theta_W} \ \ , \ \ \xi_{Af} = \frac{C'_{Lf} - C'_{Rf}}{I_3} \tag{5}$$

The final fit is obtained for the parameters: $x = -1, y_u = 2.2, y_d = 0$ [8]. There is no direct Z' coupling to leptons: it occurs only through the mixing between Z and Z', which is small ($\xi \sim 3.10^{-3}$). If the Z' strictly does not couple to leptons, no restriction can be inferred from e^+e^- and ep colliders. For the hadrophilic case [7], under the assumption

that the Z' leptonic couplings are the same as the Z ones, only very large ξ_q values are excluded from eq(4) i.e. of the order of $30 - 100$. Since under the assumption that the Z' cannot be wide one gets: $\xi_u \sim \xi_d \leq 3 - 4$[7], then the present HERA data are not sensitive to the hadrophilic Z' in the parameter range needed to accomodate LEP/SLC and CDF anomalies.

3 Restrictions from future data

We shall now discuss the restrictions to be expected at HERA at $\sqrt{s} = 314$ GeV with two luminosity options, namely $L_1 = 1000 pb^{-1}$ and $L_2 = 500 pb^{-1}$ for electrons and positrons. Assuming a Q^2 resolution $\frac{\Delta Q^2}{Q^2} = 0.5$, table 2 gives the 95% CL limits concerning the compositeness scale Λ, using a χ^2 analysis. Statistical and systematical errors have been added in quadrature. Since the systematical error is small -roughly 2% - we are dominated by the statistics in large Q^2 range we are interested into.

The main sensitivity is obtained for up quarks. We have used the GRV parametrization of structure functions[11] and checked that choice of other sets like [12], [13] leads to tiny deviations ($\sim 3\%$). Our results are weakly sensitive to the Q^2 resolution.

	Λ (TeV)	Λ_{LL}	Λ_{RR}	Λ_{LR}	Λ_{RL}
$L_1 = 1.0 fb^{-1}$	$\epsilon = +1$	8.55	8.4	8.0	7.9
	$\epsilon = -1$	8.4	8.2	7.7	7.6
$L_2 = 0.5 fb^{-1}$	$\epsilon = +1$	7.2	7.05	6.75	6.7
	$\epsilon = -1$	7.0	6.85	6.4	6.35

Table 2: HERA limits on Λ at 95% CL.

The best limits on the left left or right right chiralities are obtained from electron channel whereas the positron channel is more sensitive to left right and right left chiralities. Moreover the cross section from positron beam is characterized by a destructive interference between the photon and the massive gauge boson Z. These comments explain why the bounds on Λ_{LR} and Λ_{RL} in table 2 are slightly weaker than those on Λ_{LL} and Λ_{RR}. The fact that present HERA data restrict more Λ_{LR} and Λ_{RL} is only due to the difference in luminosity between the electron and positron beams.

These values of Λ reachable at HERA have to be compared to limits coming from others future or upgraded experiments. Firstly, Tevatron with the run II corresponding to an integrated luminosity of $L = 2 fb^{-1}$, can reach $\Lambda \sim 5$ TeV [4], and secondly, experiments measuring parity violation in muonic atoms and cesium can give bounds on Λ above 10 TeV if parity is strongly violated [14].

The mass limits on several types of "conventional" new vector bosons (of E_6, left-right origin for example) are given in table 3. SSM refers to the sequential standard model,

whereas LR_S labels the symmetric left right model and ALR the alternative one (for more details we refer to [2]).

$M_{Z'}$ (GeV)	SSM	χ	ψ	η	$\eta_\perp$	LR_s	ALR
$L_1 = 1.0 fb^{-1}$	750	470	260	290	360	500	730
$L_2 = 0.5 fb^{-1}$	630	390	210	240	300	420	610

Table 3: HERA limits on $M_{Z'}$ at 95% CL.

These bounds are not competitive with Tevatron ones since the present mass limits are around 600 GeV and will be of order 800 GeV for the run II [4]. We can note that low energy experiments, measuring atomic parity violation, are also deeply sensitive to the presence of new gauge bosons and can give limits $\geq$ 500 GeV, see [14] for further details.

Finally, we have constrained the parameter space of the hadrophilic Z' of ref. [7] under the asumption that the new couplings to leptons are identical to the Standard one's.

We give in fig. 1 the restrictions for the hadrophilic Z'[7] on the parameters ξ_{Au} and ξ_{Vu} with $M_{Z'} = 1$ TeV, setting $\xi_{Ad} = \xi_{Vd} = 0$. Now, if we allow the d-coupling to be non-zero there is, on one hand a decrease of the area of the ellipsis, and on the other hand a weak shift of the ellipsis along a direction which depends on the sign and the magnitude of the ξ_d parameters. More precisely, if ξ_{Ad} increases towards positive (resp. negative) values the ellipsis moves in the direction of negative (resp. positive) ξ_{Vu}. The same behaviour holds for ξ_{Vd} but with a weaker shift along the ξ_{Au} axis. For other values of $M_{Z'}$ the scaling formula of [7]i.e. $\xi_{Vq}, \xi_{Aq} \sim \frac{M_{Z'}}{1TeV}$ works well.
If the leptonic couplings are much weaker than the SM value, which was our working assumption, the allowed domain for Z' couplings to up quarks is much larger.

For the model of Altarelli and collaborators [8], the restriction obtained from eq(3), assuming $C'_e \sim \xi \sim 3.10^{-3}$ leads to $C'_q \sim 200$. Therefore the leptophobic Z' will escape HERA constraints.

4 Conclusions

Already with the unpolarized option the realistic future prospects for HERA will push compositeness scale in the electron quark sector in the range of 10 TeV. This limit is twice larger than Tevatron expectations and comparable to atomic parity violation prospects. Mass limits on a large class of new vector bosons like those of E_6 and left right origin, are not competitive with Tevatron. On the other hand HERA can put stringent limits on the hadrophilic Z' couplings to quarks, recently advocated to explain LEP/SLC and CDF anomalies. If in E_6 theories with orbifold compactification [15] or flipped $SU(5)$[16] the leptophobic symmetry is realized, these Z' will escape HERA tests.

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Figure Caption

Fig.1 Allowed parameter space for model of ref. [7], ξ_{Au} vs ξ_{Vu} with $M_{Z'} = 1.TeV$ and $\xi_{Ad} = \xi_{Vd} = 0$. The plain ellipsis gives the allowed domain for $L_1 = 1.0fb^{-1}$ (internal) and $L_2 = 0.5fb^{-1}$ (external); the dashed ellipsis gives the allowed domain corresponding to $\Gamma_{Z'} \leq 500Gev$.

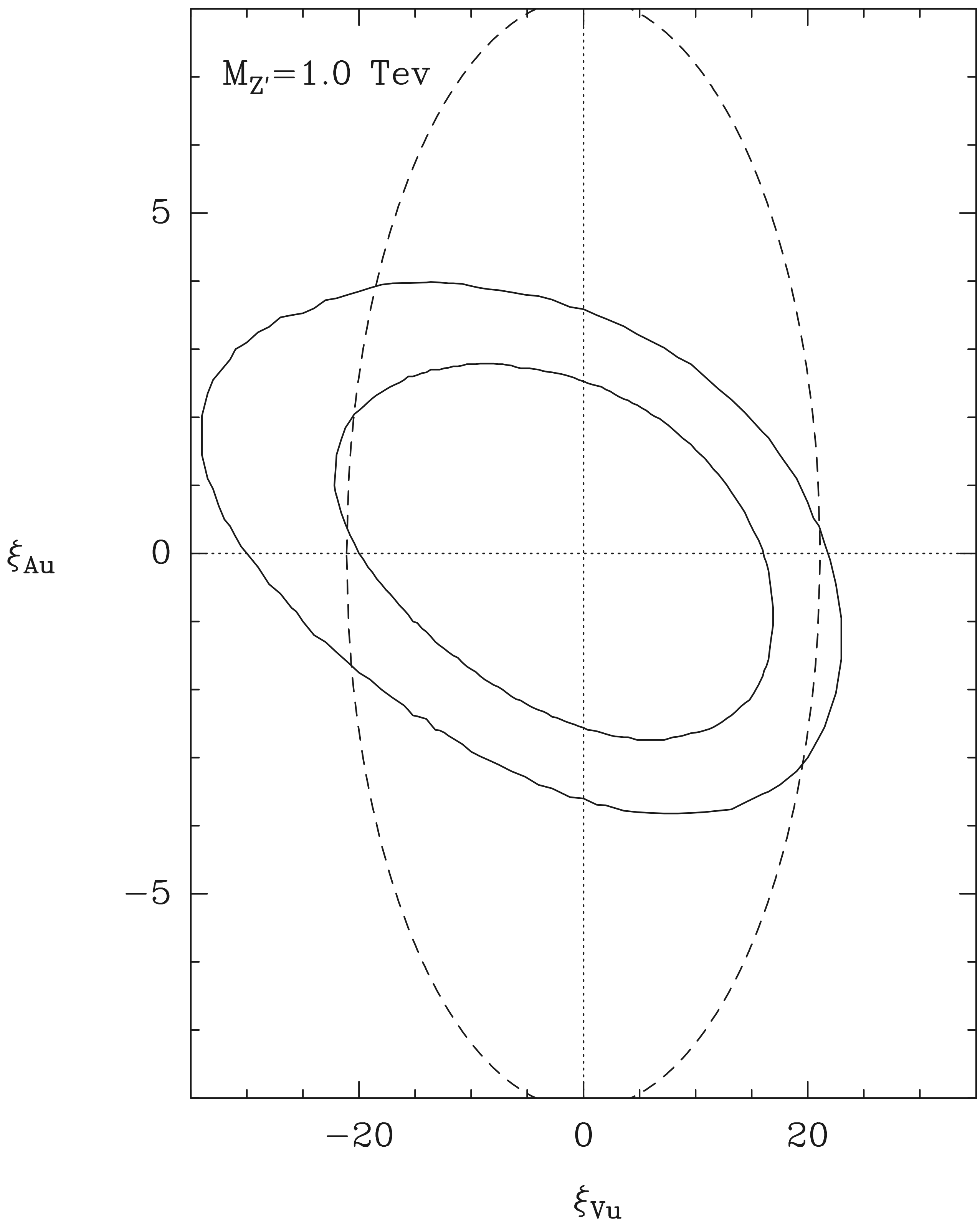

Fig 1